



# Renewable Energy Technologies for Use on the Outer Continental Shelf



## Ocean Energy Technology



### Technology Overview

- Offshore Wind
- Ocean Wave
- Ocean Current
- Ocean Tidal

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6 June 2006

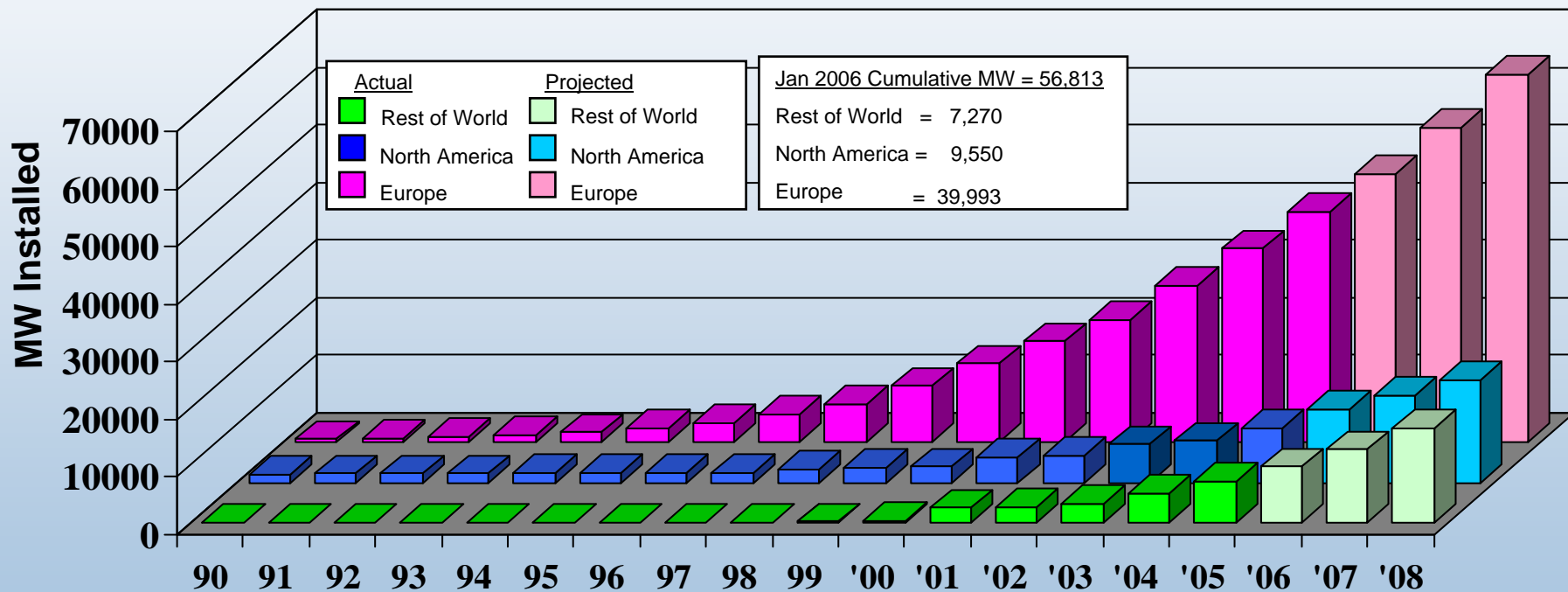
[Mike\\_Robinson@nrel.gov](mailto:Mike_Robinson@nrel.gov)

## Offshore Wind Technology

Horns Rev Denmark



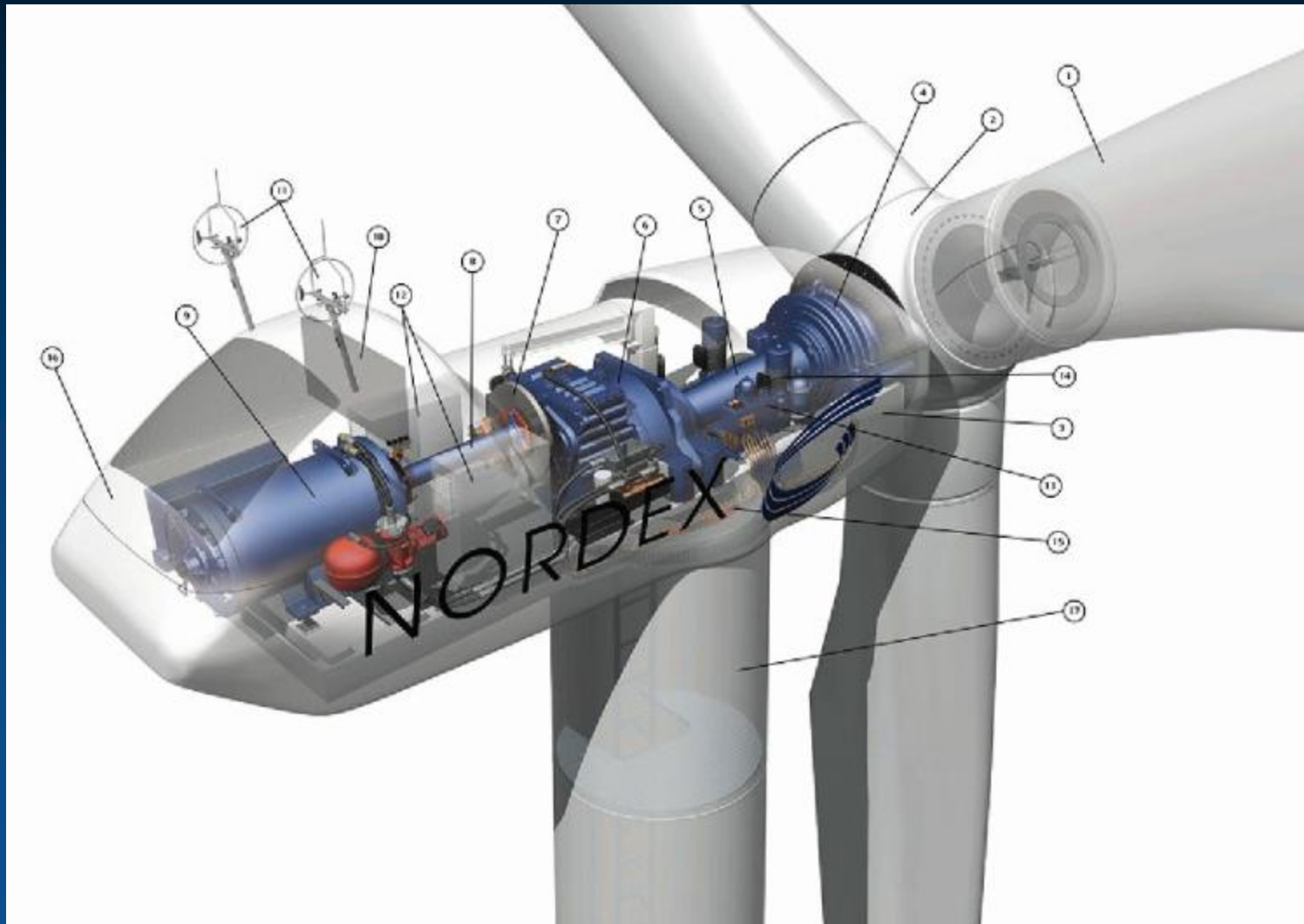
# Growth of Wind Energy Capacity Worldwide



Sources: BTM Consult Aps, Sept 2005  
Windpower Monthly, January 2006



# A Typical Large Turbine has Multiple Subsystems and Controls



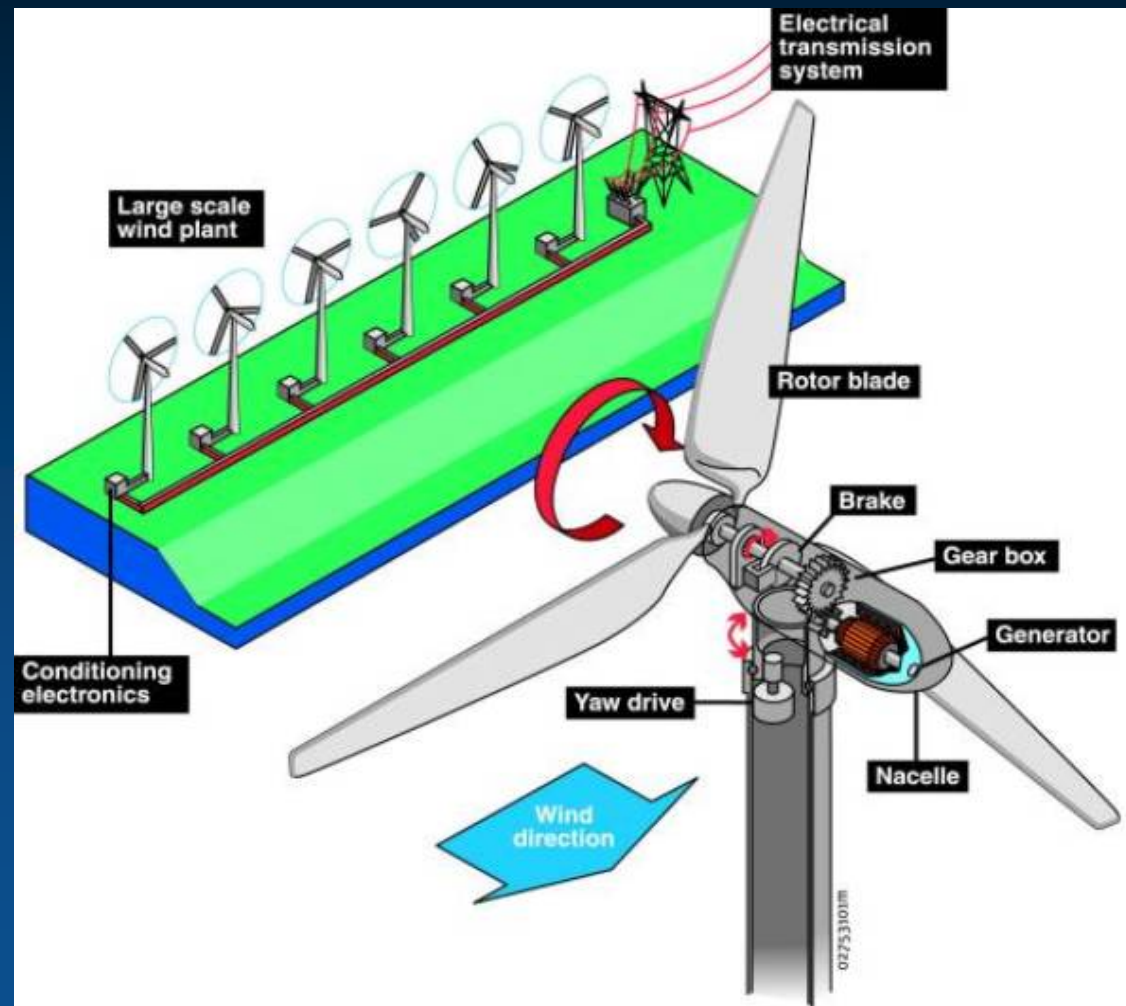


# Schematic of Wind Plant



At it's simplest, the wind turns the turbine's blades, which spin a shaft connected to a generator that makes electricity.

Large turbines are grouped together to form a wind power plant, which feeds electricity to the grid.







# Wind Turbine Power Basics

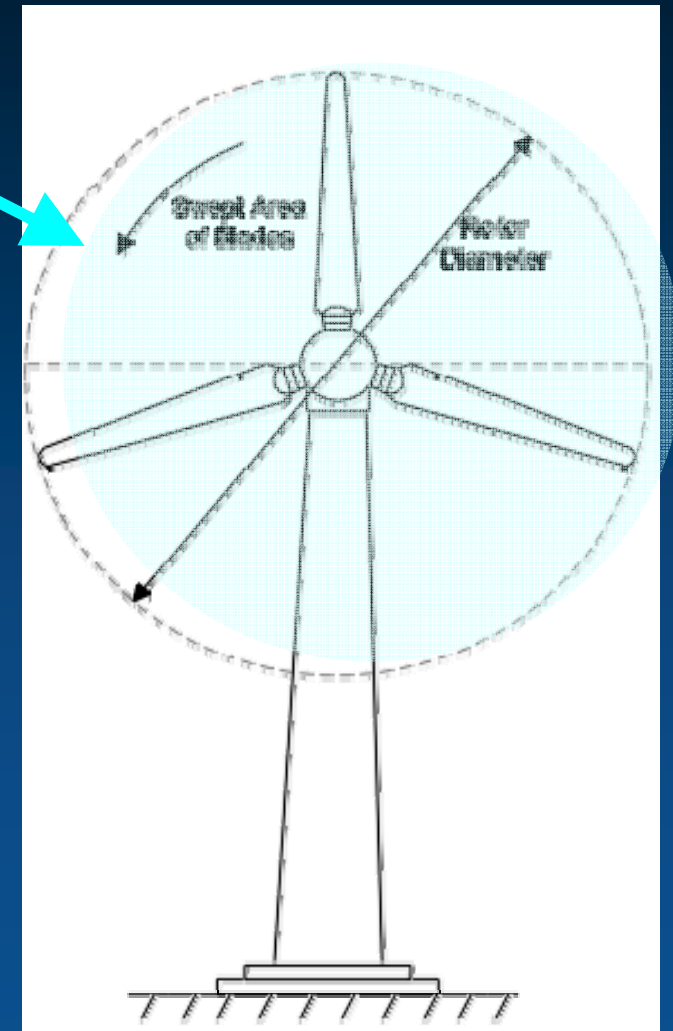
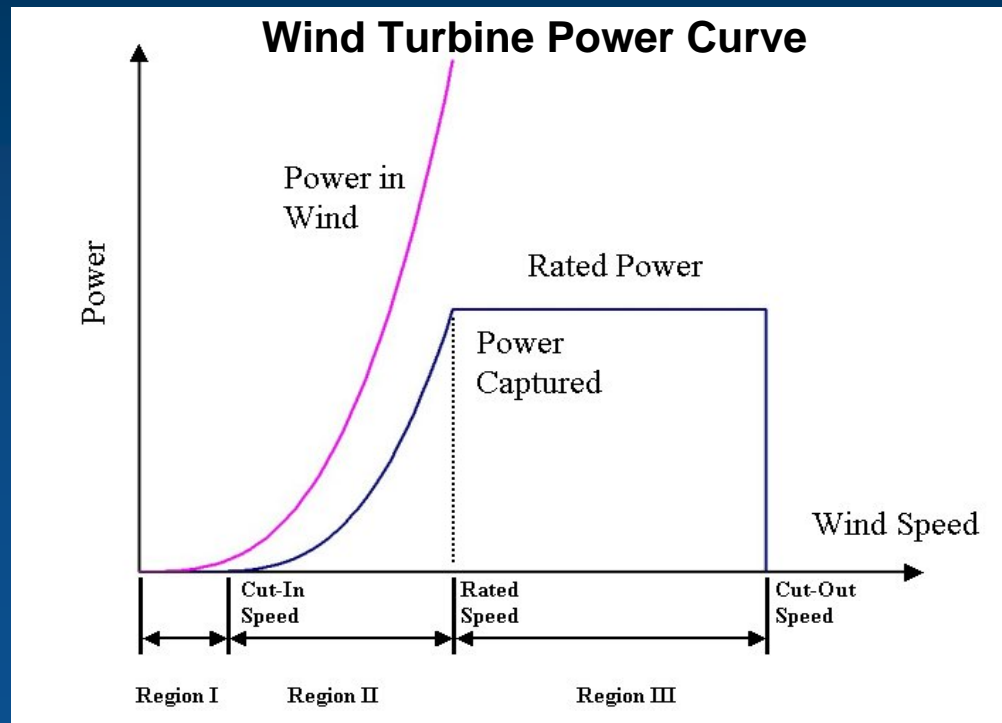


$$\text{Power in the Wind} = \frac{1}{2}\rho AV^3$$

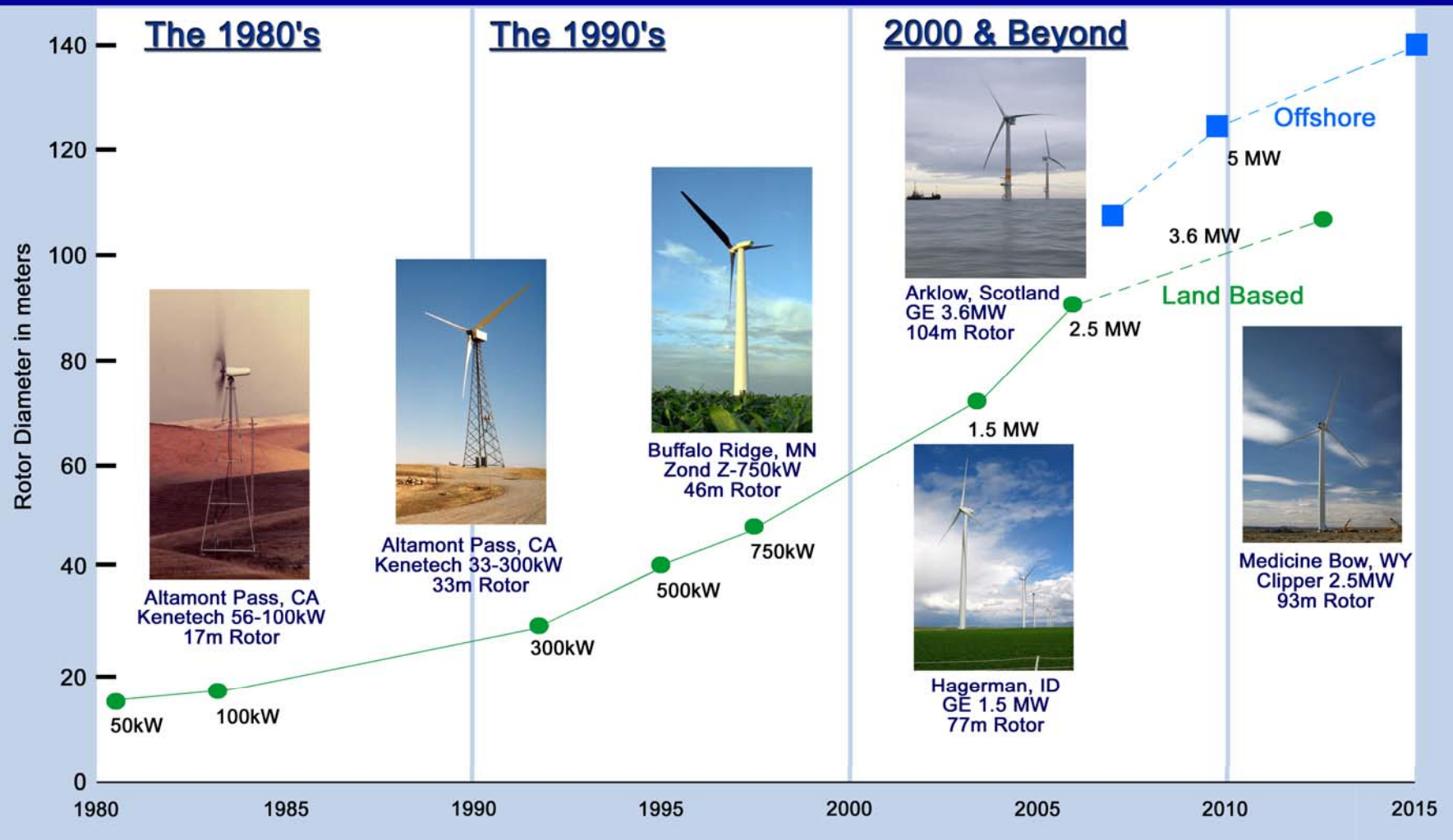
A - Area of the circle swept by the rotor

$\rho$  = Air density

V = Wind Velocity



# Evolution of U.S. Commercial Wind Technology

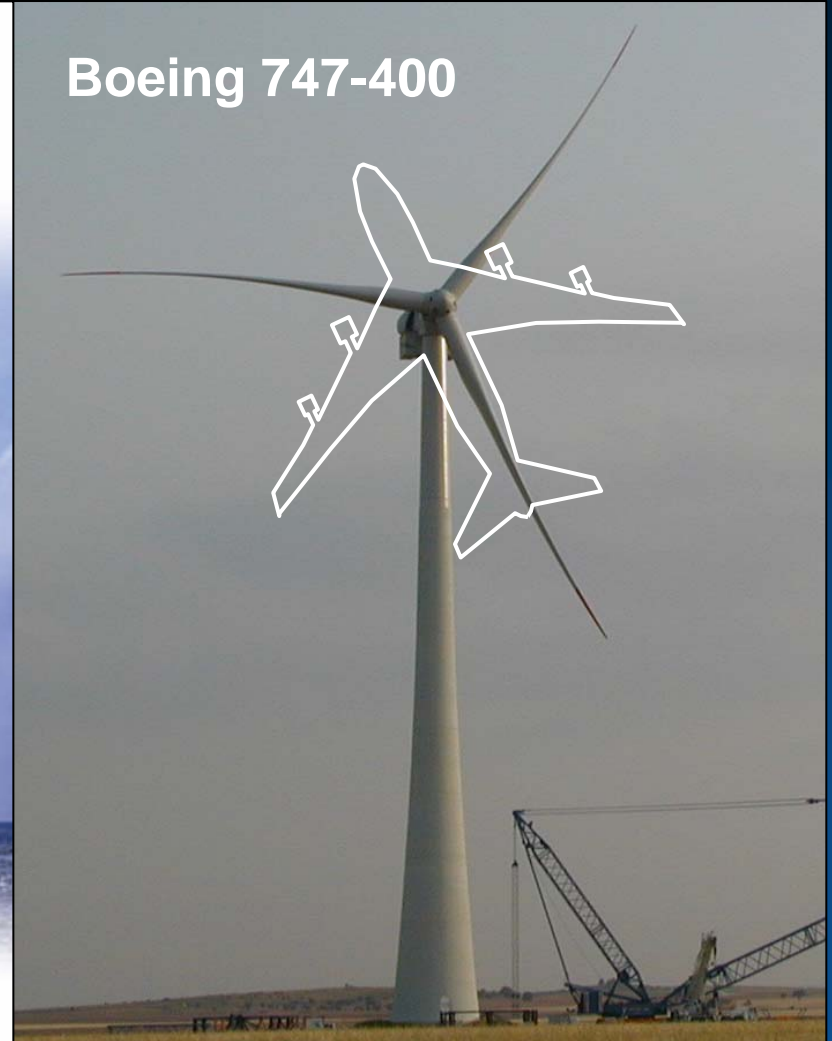




# Offshore GE Wind Energy 3.6 MW Prototype



Boeing 747-400









# Offshore Wind – U.S. Rationale

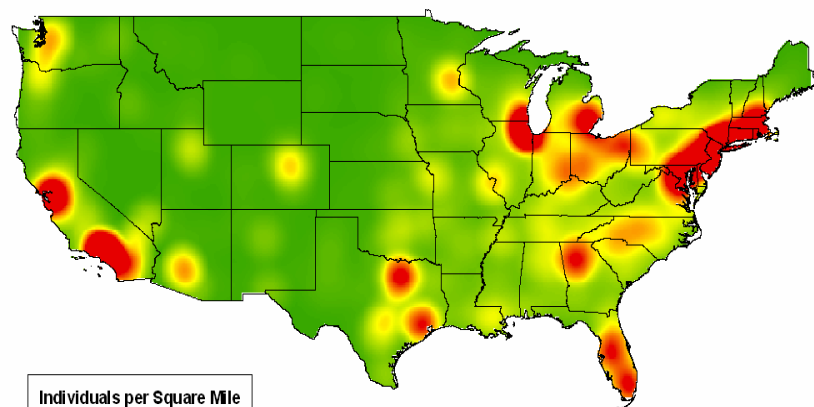
## Why Go Offshore?

*Windy onshore sites are not close to coastal load centers*

*The electric utility grid cannot be easily set up for interstate electric transmission*

*Load centers are close to the offshore wind sites*

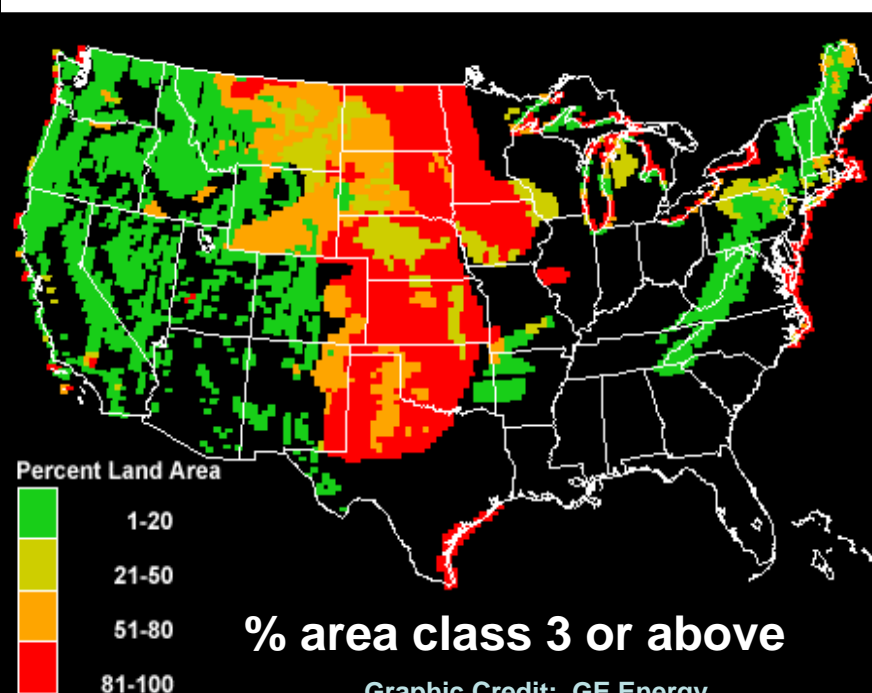
### US Population Concentration



Individuals per Square Mile  
greater than 1,000  
less than 1

Graphic Credit: Bruce Bailey AWS Truewind

### US Wind Resource



Graphic Credit: GE Energy

# U.S. Offshore Wind Energy Resource

	GW by Depth (m)			
Region	0 - 30	30 - 60	60 - 900	> 900
New England	10.3	43.5	130.6	0.0
Mid-Atlantic	64.3	126.2	45.3	30.0
Great Lakes	15.5	11.6	193.6	0.0
California	0.0	0.3	47.8	168.0
Pacific Northwest	0.0	1.6	100.4	68.2
Total	90.1	183.2	517.7	266.2



Resource Not Yet  
Assessed

U.S. Department of Energy  
National Renewable Energy Laboratory

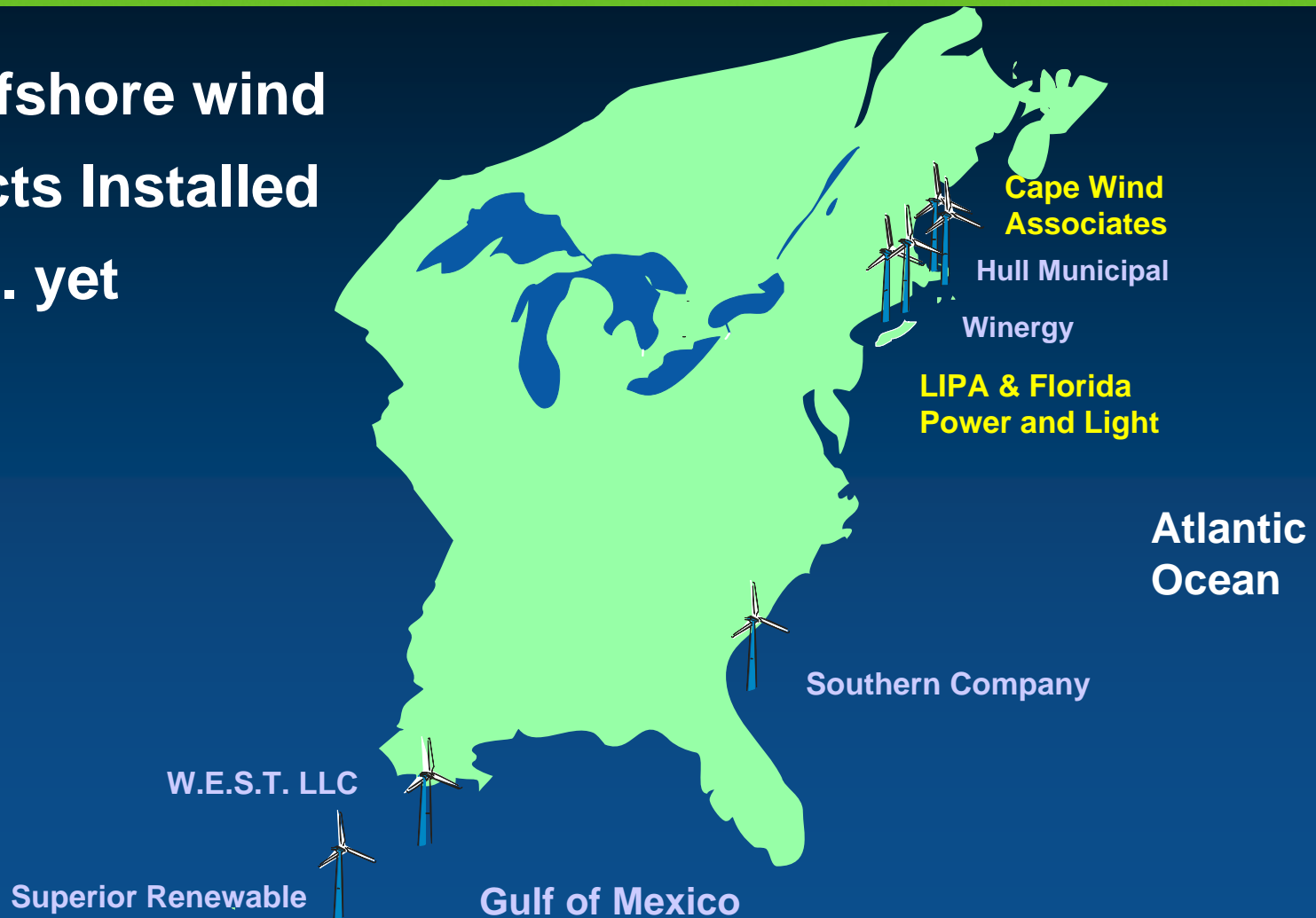




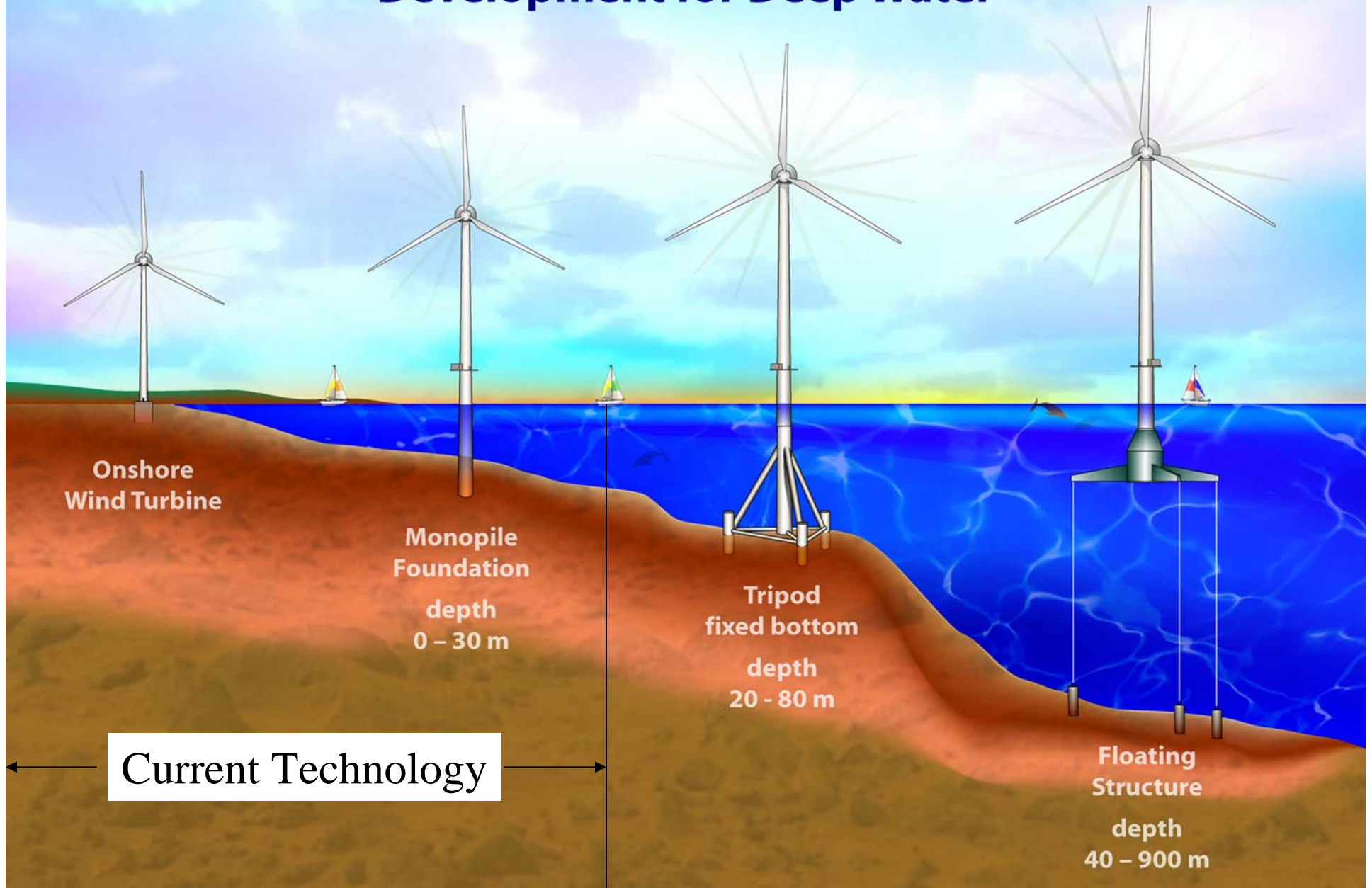
# US Projects Proposed



No Offshore wind  
projects Installed  
in U.S. yet

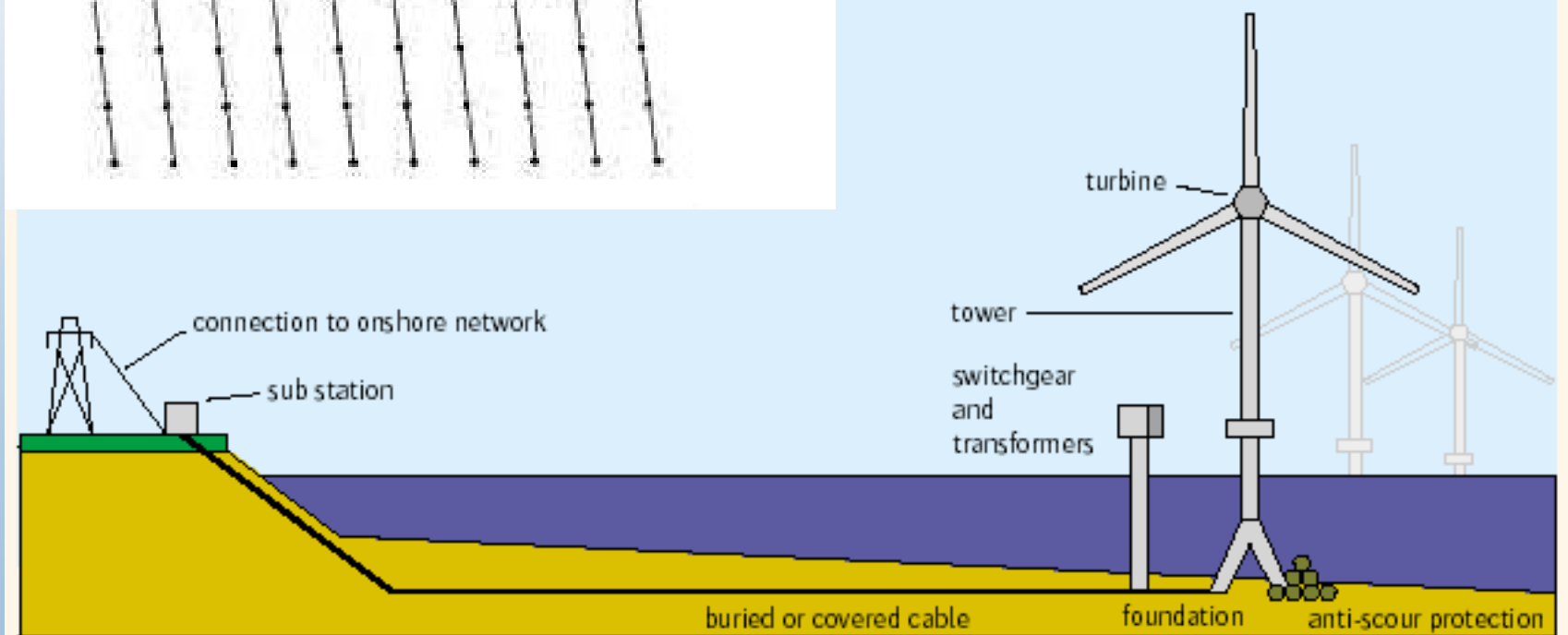
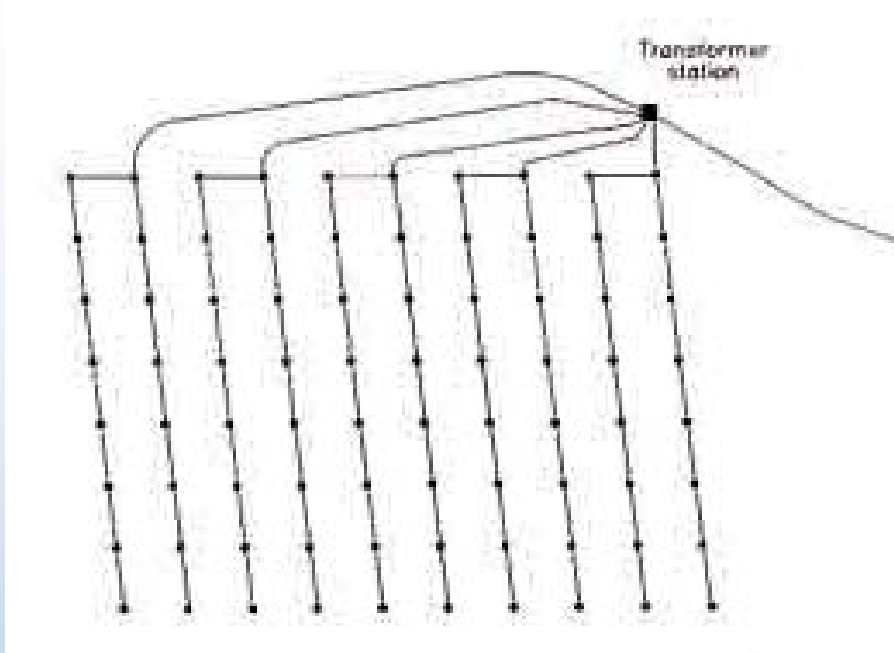


# Offshore Wind Turbine Development for Deep Water



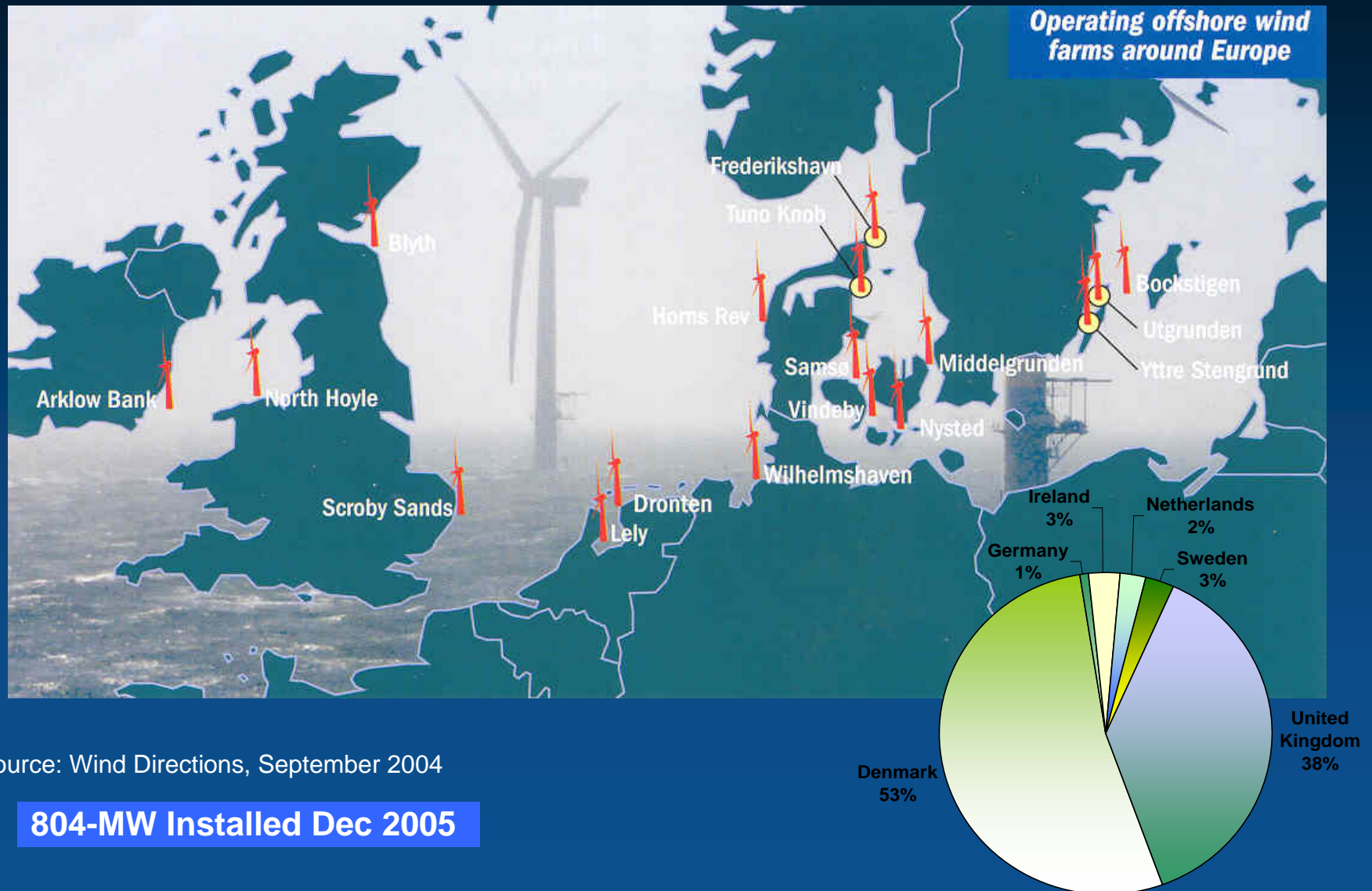


# Typical Offshore Wind Farm Layout





# Location of Existing Offshore Installations Worldwide



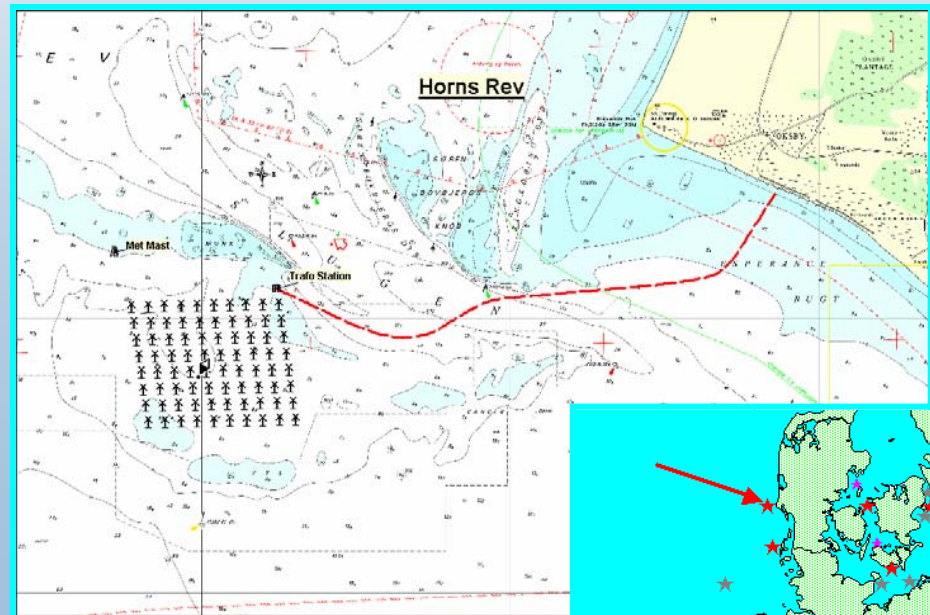
Source: Wind Directions, September 2004

**804-MW Installed Dec 2005**

# Horns Rev Wind Farm - Denmark

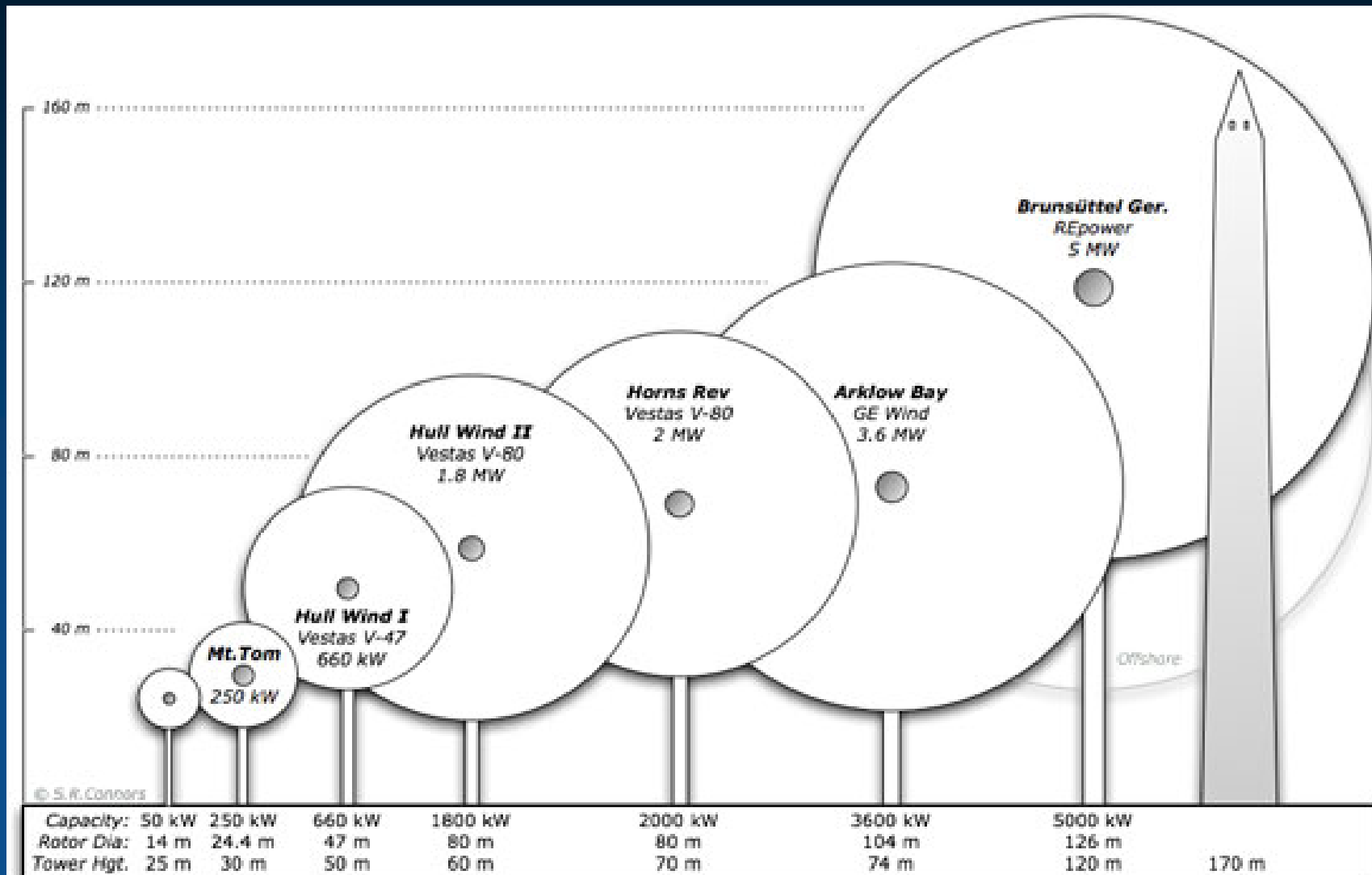


**Country:** Denmark  
**Location:** West Coast  
**Total Capacity:** 160 MW  
**Number of Turbines:** 80  
**Distance to Shore:** 14-20 km  
**Depth:** 6-12 m  
**Capital Costs:** 270 million Euro  
**Manufacturer:** Vestas  
**Total Capacity:** 2 MW  
**Turbine-type:** V80 - 80m diameter  
**Hub-height:** 70-m  
**Mean Windspeed:** 9.7 m/s  
**Annual Energy output:** 600 GWh





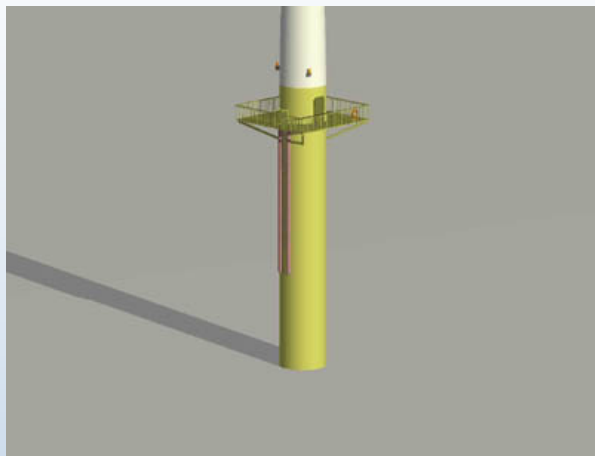
# Wind Turbine Size





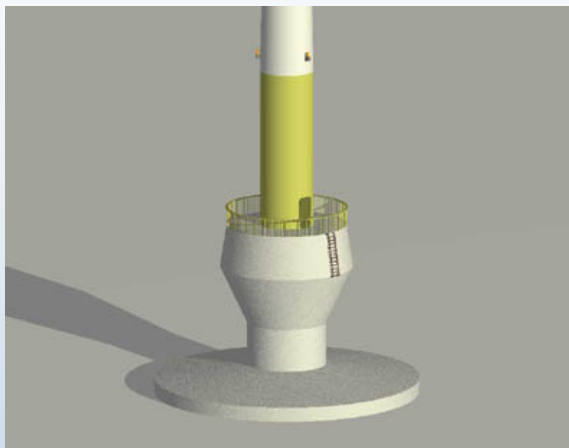
# Fixed Bottom Substructure Technology

## Proven Designs



**Monopile Foundation**

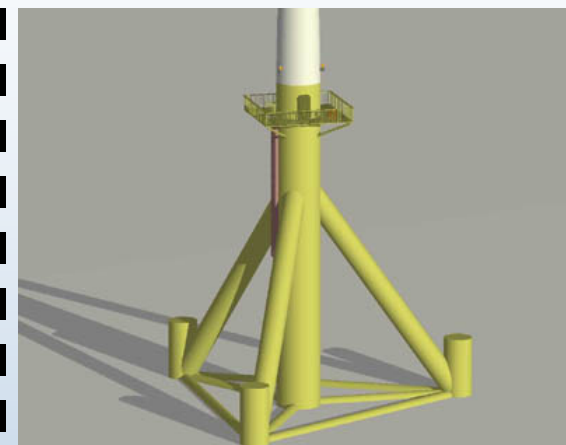
- Most Common Type
- Minimal Footprint
- Depth Limit 25-m
- Low stiffness



**Gravity Foundation**

- Larger Footprint
- Depth Limit?
- Stiffer but heavy

## Future



**Tripod/Truss Foundation**

- No wind experience
- Oil and gas to 450-m
- Larger footprint

Graphics source: <http://www.offshorewindenergy.org/>

# Arklow Banks Windfarm

## The Irish Sea

Cable Laying Vessel

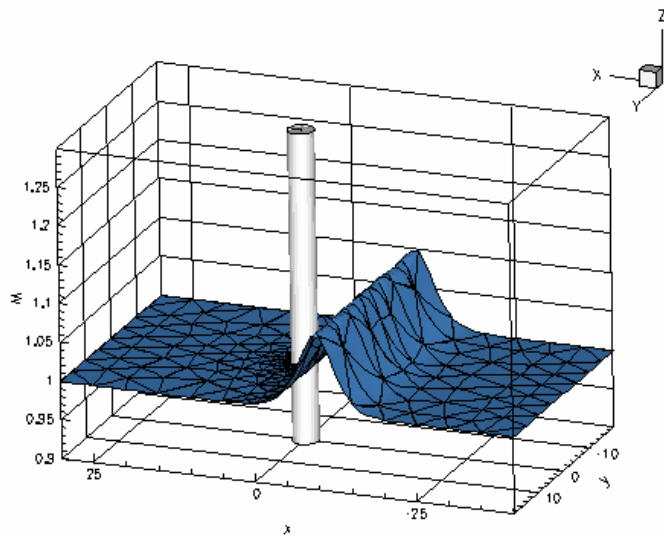
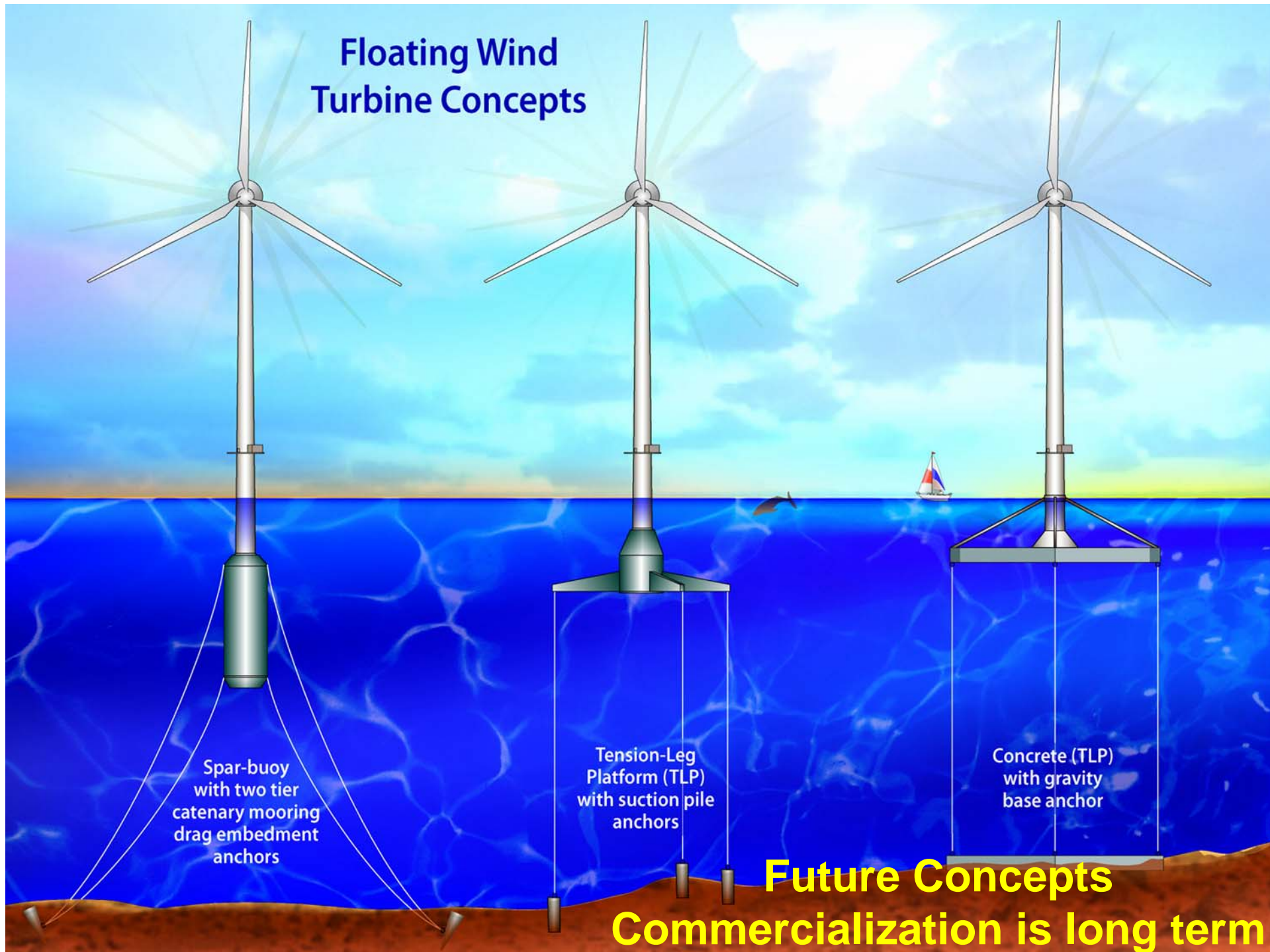
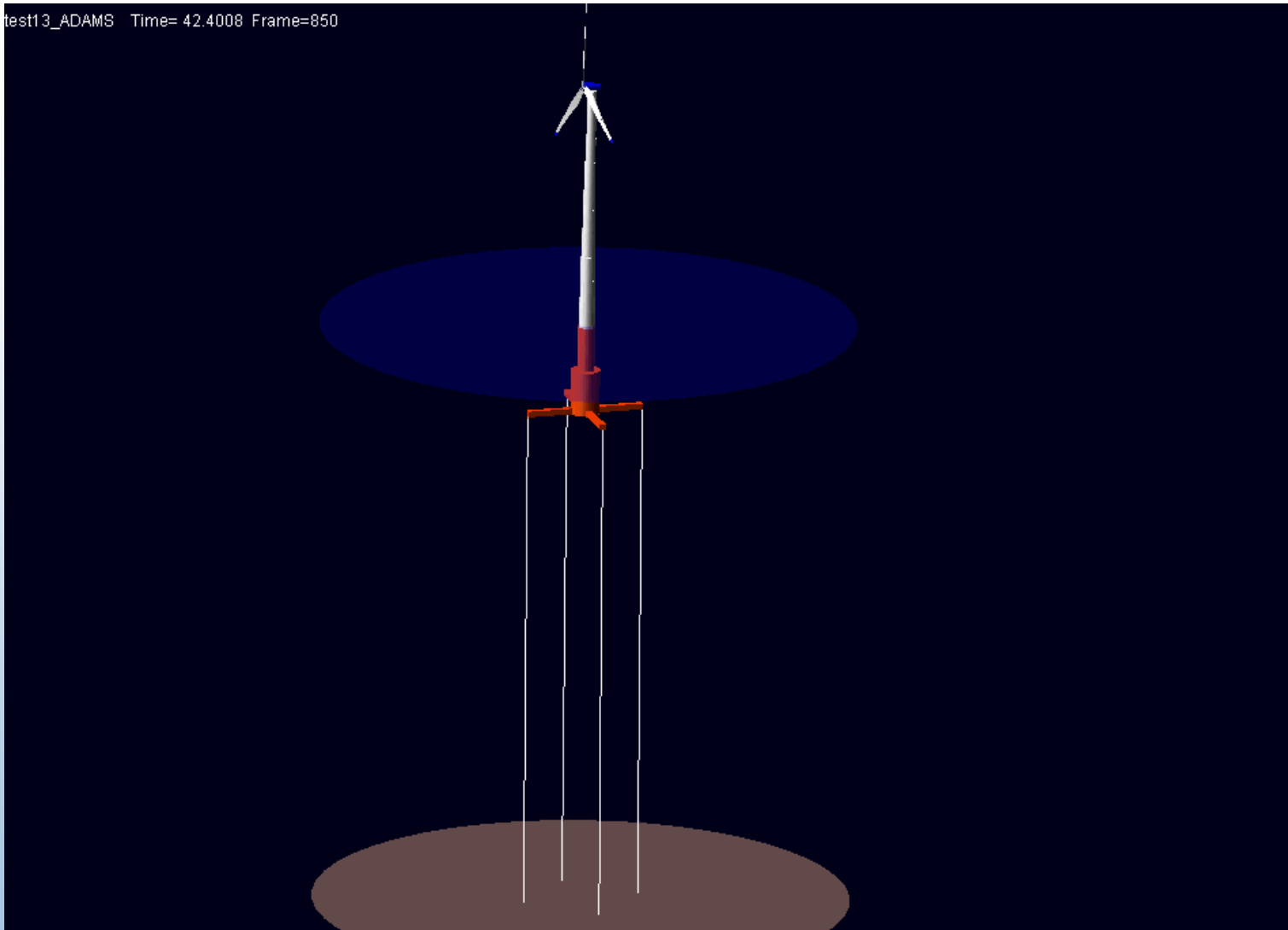


Photo: R. Thresher

## Floating Wind Turbine Concepts

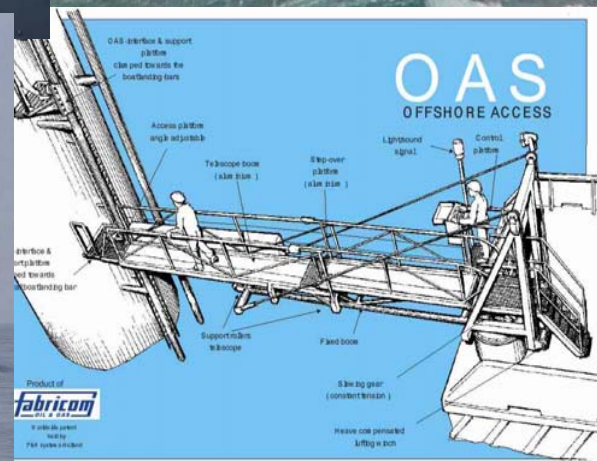
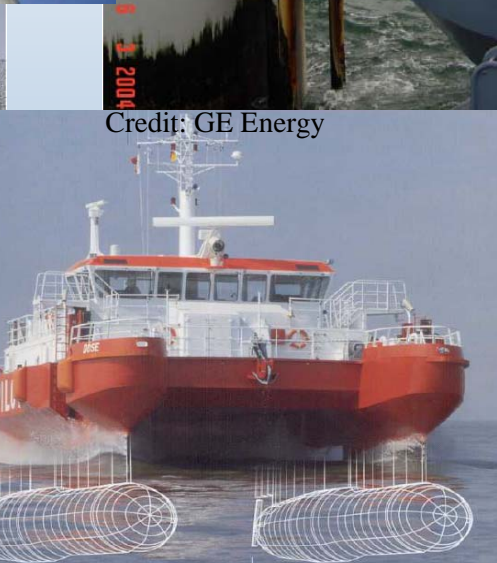
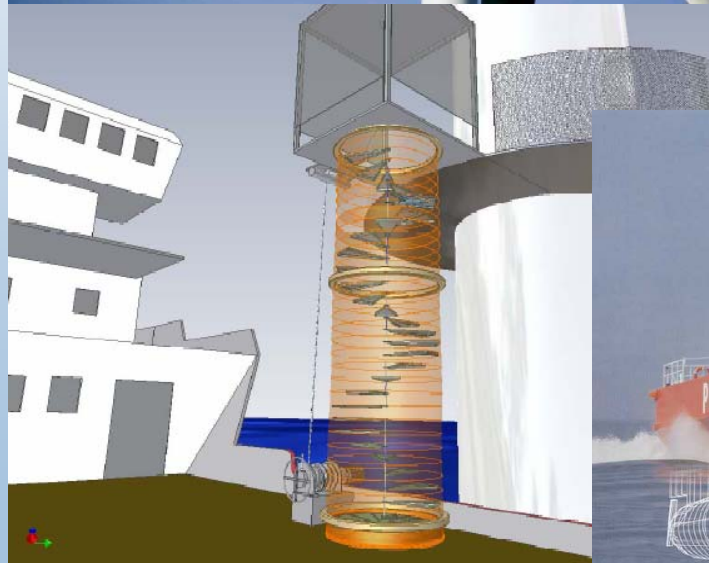


test13\_ADAMS Time= 42.4008 Frame=850





# Offshore Wind Turbine Access



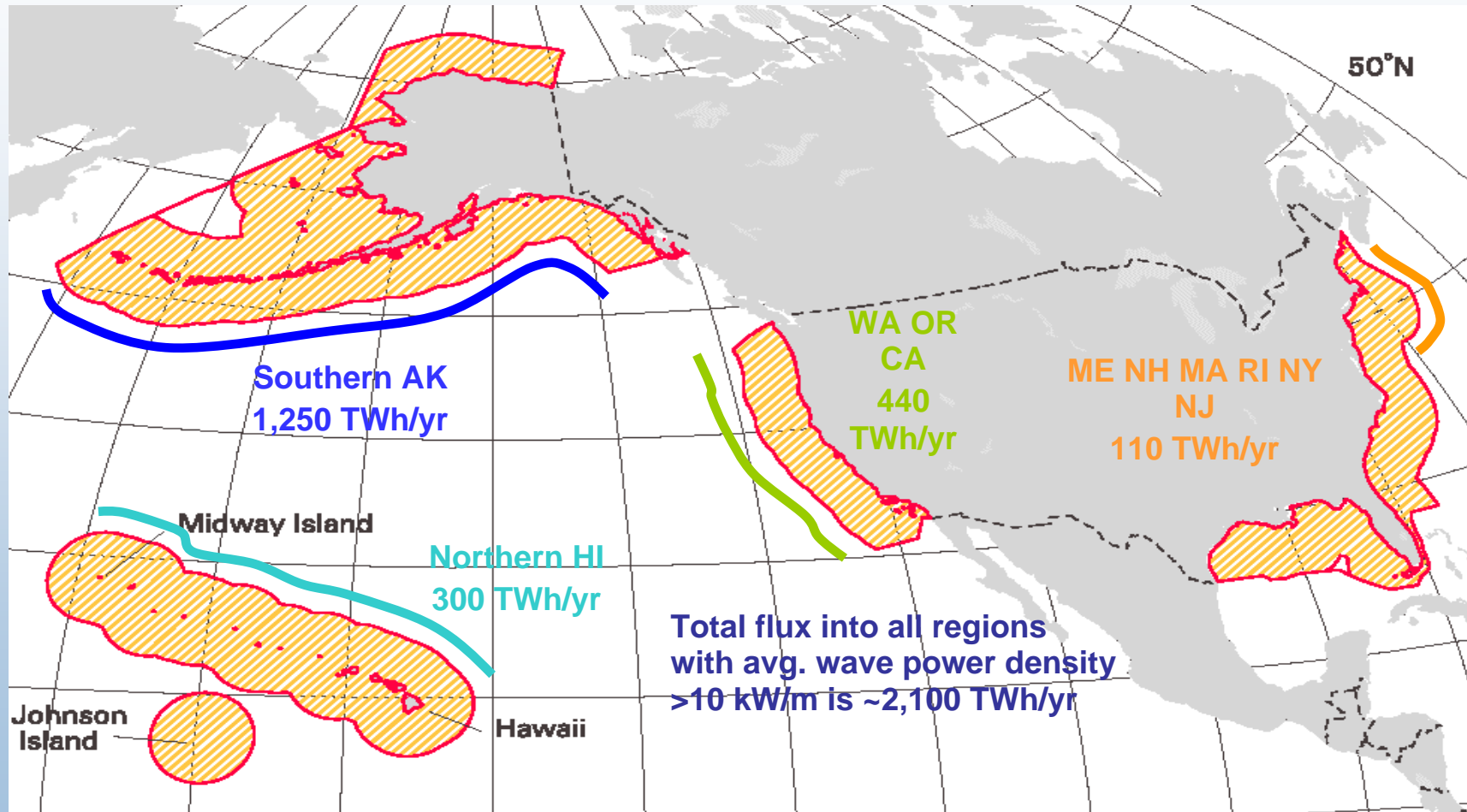
# RePower 5-MW - Worlds Largest Turbine



- 5-MW Rating
- 61.5-m blade length (LM Glasfibres)
- Offshore Demonstration project by Talisman Energy in Beatrice Fields
  - 45-m Water Depths
  - Two machines



# Ocean Wave Resource Location



Harnessing 20% of offshore wave energy resource at 50% efficiency would be comparable to all US conventional hydro generation in 2003.



# US Ocean Energy Extraction Potential



- Based on Typical Land-based Exclusions
- Offshore Wind
  - >Wind Class 5
  - 5-50nm
  - <900-m Depth
  - GOM, Alaska, Hawaii, SC, GA not included yet

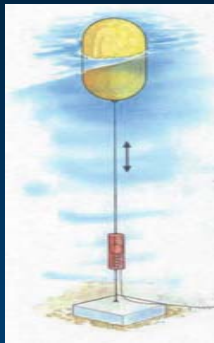




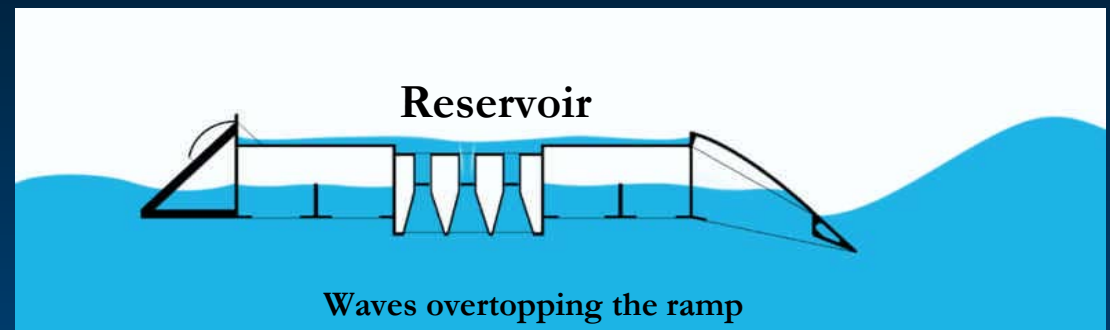
# Wave Energy Extraction Technologies



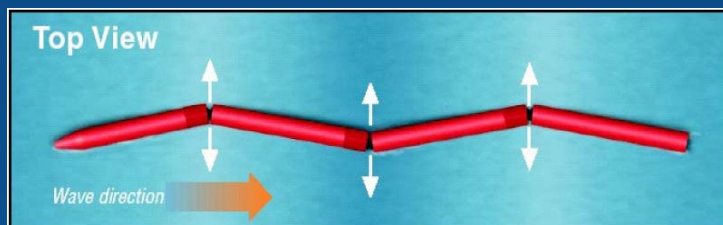
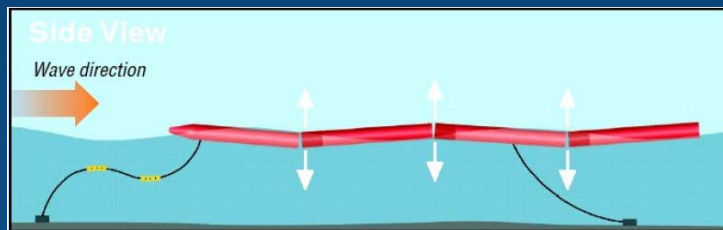
## Point Absorber



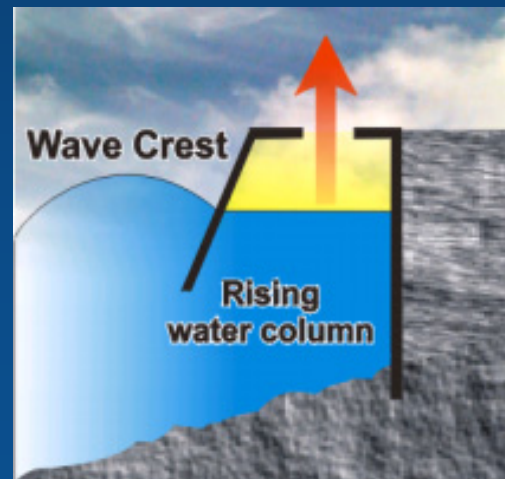
## Overtopping



## Attenuator



## Terminator OWC

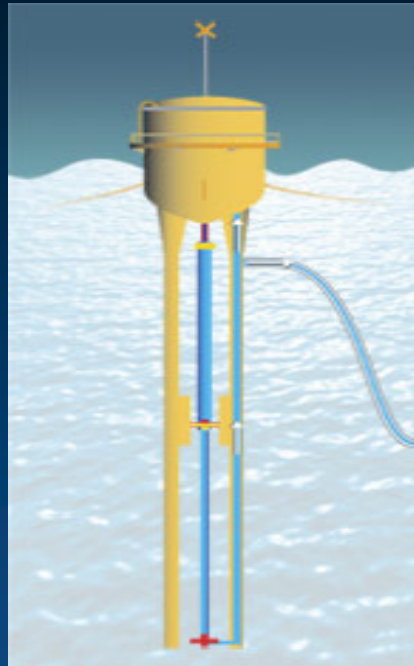




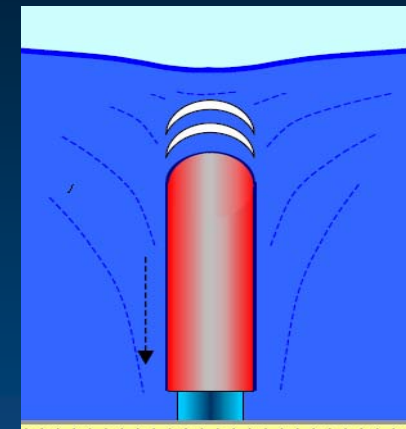
# Wave (Point Absorber) Technology Examples



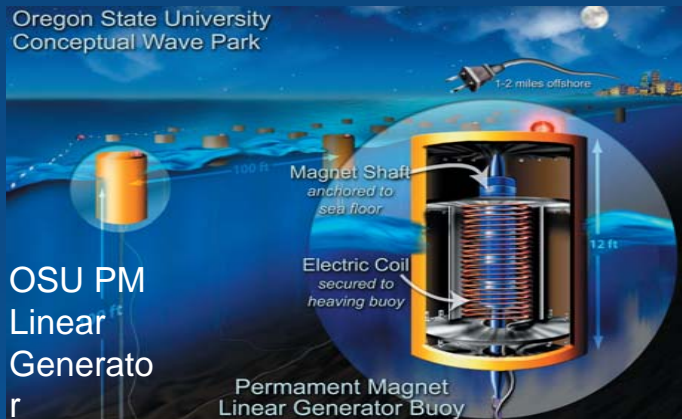
Aquabuooy;  
AquaEnergy - Makah  
Bay, WA



PowerBuoy; Ocean Power  
Technology Oahu, Hawaii



Oregon State University  
Conceptual Wave Park



OSU PM  
Linear  
Generato  
r



Archimedes Wave Swing MK I - Portugal





# Integrator Technology Example



**OPD Pelamis Being Towed to EMEC For Test Trials**



# Terminator Technology Example



Wave Dragon 1:4.5 Scale  
Prototype Under Sea Test  
in Nissum Bredning, DK





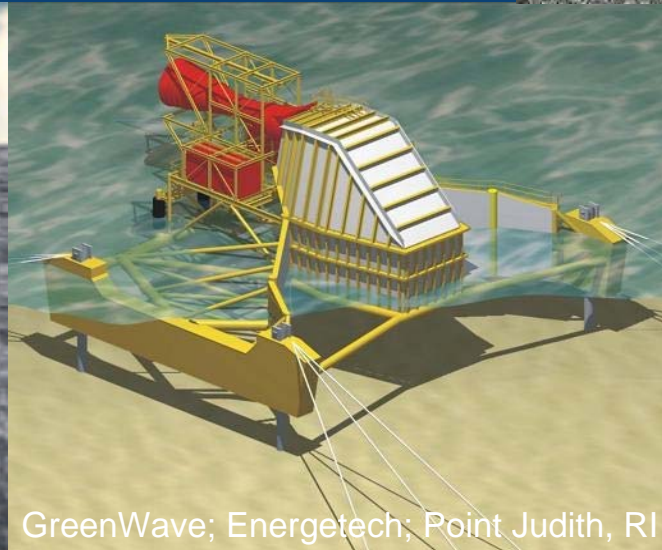
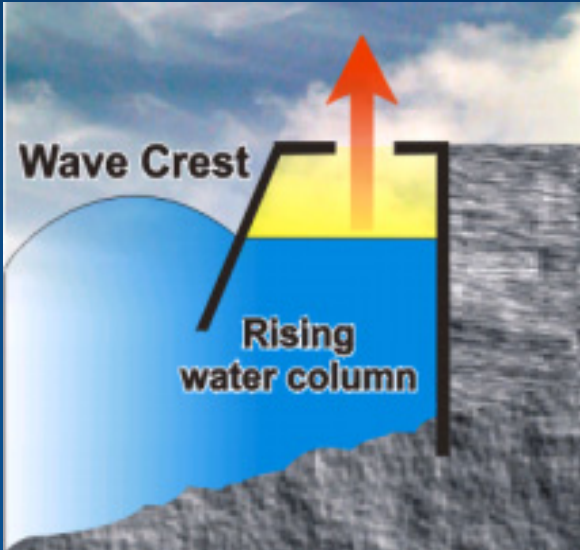
# Oscillating Water Column Technology



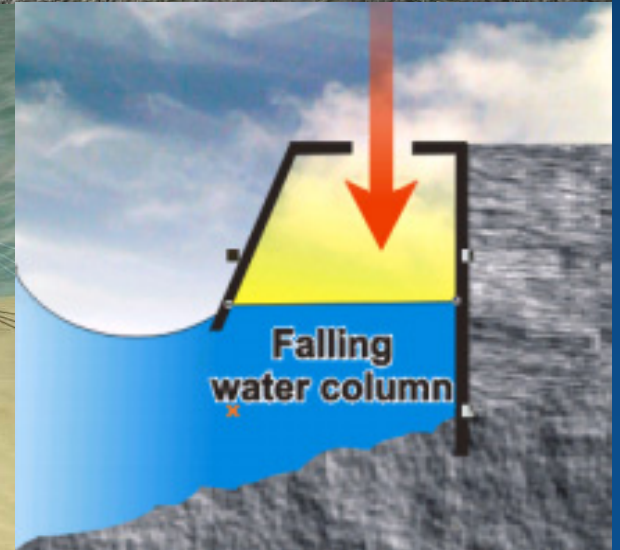
Oscillating Water Column; Energetech; Port Kembla, Australia



Wave Gen; OWC; Islay, Scotland



GreenWave; Energetech; Point Judith, RI





# North America Wave Energy Projects “Coast to Coast”

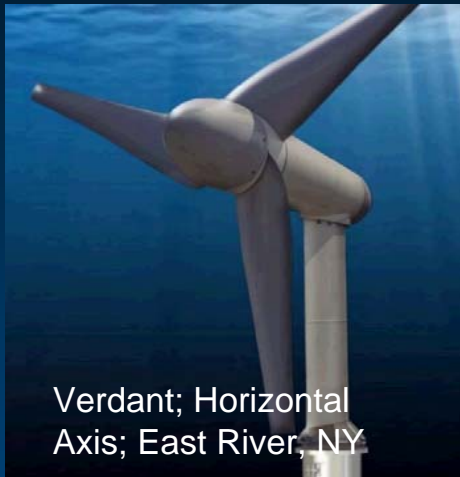


	HI, Oahu Kaneohe	WA Makah Bay	RI Point Judith	CA, San Francisco	OR Gardiner
Developer	Ocean Power Tech	AquaEnergy	Energetech	SFPUC	Oregon State University
Development Stage	Deployed June 04	Permitting since 2002	Permitting since Feb 2005	Seeking funding for permitting	Seeking funding for permitting
Device	Power Buoy™	Aqua BuOY™	OWC	Pelamis (tentative)	TBD
Size	Single buoy 40 kW	4 buoys 1 MW	Single OWC 500kW	Single Unit 750 kW	TBD
Water Depth/ Distance from Shore	30 m 1 km	50 m 6 km	2 m 2 km	30 m 15 km	TBD

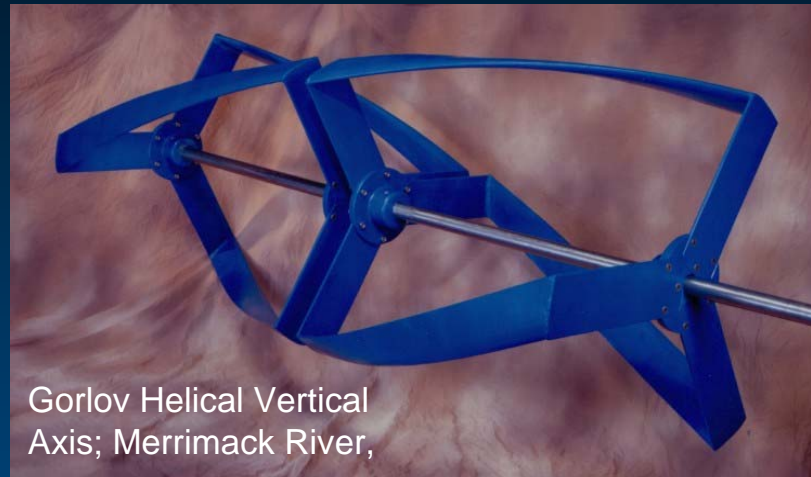




# In-Stream Tidal Technology Examples



Verdant; Horizontal Axis; East River, NY



Gorlov Helical Vertical Axis; Merrimack River,



Hydro; Open Center Turbine; Gulf Stream



Lunar Energy, Rotech Tidal Turbine



Underwater Electric Kite; Merrimack River,



MCT SeaFlow Experimental Test



# North America Tidal Energy Projects “Coast to Coast”



	MA Amesbury	NY NY, East River	BC Race Rocks	CA, SF	DE Indian River Inlet	WA Tacoma
Developer	Verdant	Verdant	Clean Currents	SFPUC Marin	UEK	Tacoma Power
Development Stage	2 Month Test Complete	Construction	NA	Formative	Permitting	Application in process
Device	Vertical axis	Horizontal axis	NA	TBD	Horizontal axis	TBD
Size	1m X 2.5 m 1 unit	5 m diameter 6 units	NA	TBD	3 m diameter 25 units	TBD
Power (kW) at Max Speed (m/s)	0.8 kW @ 1.5m/s	34 kW @ 2.1 m/s	NA	TBD	400 kW @ 3 m/s	TBD





# Offshore Wind / Wave Synergy



- Long term possibility
- Maximize Grid Interconnect Potential
- Improve Intermittency & Total Energy Output
- Increase System Reliability & Reduce Maintenance



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- Credit: GE Energy



# Summary

- Near term wind turbines in shallow-sheltered sites possible now.
- New wind technologies for deeper water are long term
- Ocean wave and current technologies are in the first prototype testing stage
- Hydrogen production – long term